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FACTORS RELATED TO NITRATE-NITROGEN CONTAMINATION OF OHIO FARM WATER WELLS

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Abstract

Livestock manure application, tillage, and rotational practices, are statistically verified as the primary sources of nitrate-nitrogen contamination in Ohio farm water wells. The elimination/reduction of these sources may be a more economically viable alternative than current end use treatments for increasing drinking water quality.

Introduction

Detection of organic and inorganic chemicals in drinking water supplies has increased societal concerns regarding health risks associated with these substances and the quality of drinking water in general. Identifying sources of contamination will provide a base of information from which modification of harmful practices can be initiated. Intensive use of petroleum based chemicals and detection of these substances in drinking water sources has implicated agriculture as a major contributor to the contamination of surface and subsurface water resources. Identifying the source and extent of contamination is required before an effective remediation or resolution of the problem can be achieved.

This paper focuses on one aspect of water quality concerns--identifying possible source(s) of nitrate-nitrogen contamination in Ohio's farm water wells. Generally, nitrate-nitrogen is classified as a non-point source of contamination. This research helps identify the source(s) of nitrate-nitrogen associated with detectable levels. Identifying sources of nitrate-nitrogen may allow for more effective and efficient remediation efforts. Eliminating or reducing the source(s) of nitrate-nitrogen may be an economically viable alternative to current end-use treatment of drinking water. In order to determine the economic efficiency of alternative remediation strategies, source identification as well as economic benefits and costs for each remediation alternative must be obtained.

The majority of contributions to the literature dealing with aspects of groundwater quality center around well monitoring, lysimeter testing, and watershed runoff observations. Although these testing procedures are necessary, the costs associated with these forms of testing are at times prohibitive. To minimize costs, models have been developed to mathematically simulate the movement of surface level contaminations toward and into the aquifer. These models often require large quantities of data, which may or may not be readily available for a specific region or area under investigation. Modeling, which aggregates the hydrogeological characteristics of an area in an attempt to estimate susceptibility to contamination is extensively reviewed in Rausch (1992), and provides the foundation for the nitrate-nitrogen statistical model discussed in the next section.

Methodology

A comprehensive conceptual model was developed and presented in Rausch (1992). This model was modified in a preliminary statistical estimation based on both theoretical correctness and statistical significance of the coefficients of independent variables. The final multiple regression model developed in this study incorporates estimated nitrogen availability, site specific and hydrogeological characteristics in an attempt to explain observed levels of contamination from nitrate-nitrogen. The model for estimating nitrate-nitrogen contamination is

$$\begin{aligned} Nitrate - nitrogen = \alpha + \beta_1 DRASTIC + \beta_2 WELLDEPT + \beta_3 YRDRILL + \\ \beta_4 LNFEED + \beta_5 LNCROP + \beta_6 DTILL + \beta_7 DROTATE + \beta_8 MFERT + \epsilon \end{aligned}$$

Where; Nitrate-nitrogen = nitrate-nitrogen concentration in well water test in mg/l;

α = intercept term;

DRASTIC = aggregate county level pesticide pollution potential index;

WELLDEPT = estimated depth of well in feet;

YRDRILL = year in which the well was drilled;

LNFEED = distance from well to feedlot in log(feet);

LNCROP = distance from well to cropland in log(feet);

DTILL = 1 if conservation tillage system used, otherwise 0;

DROTATE = 1 if rotation system includes meadow, otherwise 0.

MFERT = estimated application rate (tons(active ingredient)/ac.) of livestock manure;

ϵ = error term.

Nitrate levels are quantified levels (in milligrams per liter) of nitrate-nitrogen contamination detected in individual well observations. It is chosen as the dependent variable since it serves as the best estimate of groundwater quality available for the region.

Movement of surface applied chemicals is a function of many hydrological and geological factors specific to a given area. These factors have been aggregated into seven distinct hydrogeological characteristics for the specified area, and they form the DRASTIC model (Aller et al., 1987). The DRASTIC model will serve as a proxy for the hydrogeological characteristics associated with the movement of surface applied agricultural nitrogen sources. The use of this model assumes that the major factors which control leaching of agricultural nitrogen sources into the aquifer are best captured by these seven variables. Thus, the DRASTIC index values should have a strong positive correlation with known levels of contamination.

The quantity of nitrate-nitrogen which leaches through the vadose zone and into the aquifer is a function of several factors, one of which is the quantity of nitrogen available. For nitrates this is a function of commercial fertilizer use, livestock manure application rates and rotation practices that incorporate nitrogen fixing cultivars such as legumes. The quantity of nitrate-nitrogen available is expected to be positively correlated with detection levels. The conceptual model in Rausch (1992) disaggregates possible agricultural sources of nitrogen into commercial fertilizer applied and livestock manure applied. Nitrogen obtained from diversity in crop rotational practices will be captured by another variable.

The depth of the well is expected to be negatively correlated with nitrate-nitrogen contamination. As well depth increases, nitrate sources must travel further to reach the aquifer, thus, increasing the probability that the contaminate will dilute, degrade or be used by plants.

The year in which the well was drilled is also expected to be positively correlated with the associated level of nitrate contamination. Older wells are expected to be in less than optimal working condition simply because of years in service. As the age of the well increases deterioration of the well casings and structural attributes of the well are also expected to increase, thus increasing the probability of surface and near surface level contaminates entering the aquifer and well.

Site specific variables (distances to feedlot and/or cropland) are characteristics unique to each individual well that affect nitrate-nitrogen detection. As distances increase, contaminates must travel farther, and so the probability of dilution, degradation or plant uptake of the contaminate also increases. Groundwater movement within the wells area of influence is a non-linear function, and is best captured by an exponential function (Harrold, Schwab and Bondurant, 1986). Thus, sources of contamination closer in proximity should carry an increased weight associated with their distance from the well. This weight can best be captured with a log-linear function.

Tillage practices account for the dummy variable DTILL and are categorized into two distinct groups by increasing surface residue levels. As surface residue is increased, infiltration rates tend to increase as does the probability that excess nitrate-nitrogen will leach into the saturated zone with the increase in deep percolation (Baker, 1987). The heaviest residue levels are expected with conservation tillage practices. With reduced tillage one expects increases in the porosity and macro pore structures of the soil relative to conventional forms of tillage (Walter et al., 1987; Ehlers, 1975). As these characteristics increase, infiltration, percolation, and nitrate-nitrogen movement are also expected to increase (Dick and Daniel, 1987). Conversely, conventional tillage may reduce groundwater contamination levels because of decreases in infiltration rates associated with less surface residue.

Dummy variable DROTATE differentiates between rotation practices. Although there are many rotational practices, two distinct practices stand alone in their potential to increase organic matter, and infiltration rates, possibly resulting in the leaching of available nitrogen reserves. As the rotational practices incorporate forage, meadows, and legumes, the organic matter and infiltration rates generally will also increase. As infiltration and availability of nitrogen increases, the potential for leaching of nitrate-nitrogen below the root zone and into the saturated zone will also increase. Thus, rotational practices will be distinguished as those which incorporate forage, meadows, and legumes, from those which do not. If the rotation practice includes a significant amount of legumes, it may be positively correlated with nitrate-nitrogen detection levels. However, if the rotation incorporates primarily a meadow or non-leguminous forage, a negative correlation may be expected. Under the non-legume scenario an increase in the presence of a grass or meadow would decrease the quantity of nitrogen available for leaching because of plant uptake, and therefore a negative effect on nitrate-nitrogen detection would be expected. More forages in the rotation also imply that less corn is grown, and total application of nitrogen fertilization are generally lower.

The data required to operationalize the nitrate-nitrogen model are obtained from primary and secondary sources. The U.S. Environmental Protection Agency (Alexander et al., 1985) is the source of county level DRASTIC indexing values. Heidelberg College's Water Quality Lab (Baker et al., 1989) is the source of information regarding site specific characteristics and nitrate-nitrogen detection levels associated with individual water wells. The Ohio Farm Household Longitudinal Survey (Stout et al., 1989) provides agricultural production practices, which when supplemented by primary data collection, provide more precise estimates of the distances from possible sources of nitrate-nitrogen to individual wells.

Analysis and Results

Estimates for the coefficients in the nitrate-nitrogen model were made with the data obtained from observations common to both the Longitudinal Survey and Heidelberg water quality data. Due to incompleteness in survey respondents only 22 of the 81 total observations have full information with respect to the nitrate-nitrogen model specifications, but representativeness of the sample is maintained (see Rausch (1992). The model and statistical results presented in

Table 1 are based upon the findings associated with these 22 complete sets of observations.

The full information version of the nitrate-nitrogen model with eight variables explains 86.6 percent of the variation ($\bar{R}^2$) in nitrate-nitrogen detection levels in Ohio farm wells. All eight variables are statistically significant at or below the 12 percent level, three are highly significant at or below the 1 percent level, three at the 4.2-4.8 percent level and two between the 10-12.6 percent level (Table 1). All variables estimated in this model have the predicted sign.

The three variables having the highest significance level are associated with agricultural production practices. Livestock manure application (MFERT) is the strongest variable explaining positive variations in detectable levels of nitrate-nitrogen suggesting that for every pound of nitrogen obtained from livestock manure (active ingredient basis) well water nitrate-nitrogen detection is expected to increase by 0.04 mg/l holding all other variables constant. Earlier research by Diallo (1990) suggested that nitrogen credits associated with the use of livestock manure may not be properly accounted for at the farm level. Thus, the possibility of over application of nitrogen and other nutrients found in livestock manure may explain the positive correlation between livestock manure application and nitrate-nitrogen detection.

The significance of the dummy variable associated with tillage practices (DTILL) suggests that reductions in soil disturbance and surface run-off from conservation tillage may increase the detection of nitrate-nitrogen concentration by 2.41 mg/l on average.

The third highly significant variable is the dummy variable which captures rotational practices. The coefficient for DROTATE is negative which means that

Table 1 Aggregate Nitrate-Nitrogen Model Results; R^2, $\bar{R}^2$, F-statistic, F-significance, variables, t-statistic and t-significance for 22 Ohio farms (1988).

R Square	.91760
Adjusted R Square	.86689
Standard Error	.79727

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	8	92.01600	11.50200
Residual	13	8.26331	.63564

F = 18.09516 Signif F = .0000

Dependent Variable.. NITRATE

------------------ Variables in the Equation ------------------

Variable	β	SE β	T	Sig T
WELLDEPT	-.010826	.004802	-2.255	.0421
MFERT	.031669	.005180	6.114	.0000
LNCROP	-.564373	.250580	-2.252	.0422
DROTATE	-1.445680	.414445	-3.488	.0040
YRDRILL	-.017082	.009671	-1.766	.1008
DRASTIC	.029736	.013597	2.187	.0476
DTILL	2.414995	.555531	4.347	.0008
LNFEED	-.334490	.204395	-1.636	.1257
(Constant)	35.177895	19.205920	1.832	.0900

there is less nitrate-nitrogen in wells where a rotation is practiced on the farm. The variable decreases the occurrence of nitrate-nitrogen detection by 1.45 mg/l in private water wells, holding all other variables constant. DROTATE is significant at the <1 percent level.

The final two variables relating agricultural production practices to nitrate-nitrogen detection levels are the logs of the distances that crop land and feedlot facilities are from the well site. As the distance these sources are from the well site increases, the detection of nitrate-nitrogen decreases. Thus, the signs of these variables are negative and significant at the 4.2 percent and

12.6 percent level respectively. As the distance to crop land and feedlot facilities increases, one would expect the detection of nitrate-nitrogen to decrease by 0.56 and 0.33 mg/l per log(foot) of movement away from the well site, respectively.

The last three variables describe well and hydrogeological characteristics. The first variable captures the depth of the well (WELLDEPT). It has the expected negative sign and is significant at the 4.2 percent level. While holding all other variables constant, increasing well depth by one foot decreases nitrate-nitrogen detection by 0.011 mg/l.

DRASTIC, which captures hydrological and geological characteristics, is significant at the 11.4% level and is positively correlated with nitrate-nitrogen detection.

The final variable accounts for the year in which the well was drilled (YRDRILL) has the lowest response rate of all variables presented. The YRDRILL variable is negatively correlated with detection levels, as expected, and significant at the 10.1 percent level.

Conclusions

The evidence presented would suggest that detectable nitrate-nitrogen contamination is due to agricultural manure application, tillage, and rotational practices in proximity to the aquifer rather than from site specific sources such as septic systems, well casing which do not extend above surface grade, or those casings deteriorating from age. Thus, agricultural practices as efficient remediation strategies become relevant.

If production practices are primary sources of contamination and remediation efforts are targeted at these sources, then the domain of efficient remediation strategies could be expanded. With only site specific characteristics effecting nitrate-nitrogen detection, remediation efforts could be as direct as well site modification. However, with the inclusion of agricultural production practices, potential remediation efforts are expanded. It is conceivable that in areas where rural and urban activities are in close proximity agricultural practices over common aquifer(s) may lead to property rights disputes. Thus, clear and concise definitions of property rights will have to be established.

Information is also needed on actual expenditures as well as willingness to pay (WTP) for remediation of groundwater contamination if economically efficient solutions are to be found. A preliminary analysis of these factors by Rausch (1992) finds a limited amount of remediation directly related to nitrate-nitrogen contamination of Ohio farm water wells. Preliminary estimates of WTP values for alternative nitrate-nitrogen threshold values defined by individual respondents found a large range (e.g., \$0 - \$4,500). Further analysis is in progress.

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